

Strip Flatness Prediction in a 4 High Tandem Mill Using a Dynamic Model.

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Abstract: Some defects on the strip flatness could appear during the cold rolling, such as waves at center of edges. There are factors that influence the strip shape during the process including variables such as rolling speed, strip width, materials properties, forces at the entrances and exit of the rolling mill, elastic deflection, work rolls crown. In this work how the strip, the crown and the rolls behave during a cold rolling process in a 4 high tandem mill composed by four stands, and how their behavior create the strip shape are being studied. For developing the model a study of the mesh density, element type in the selected mesh, boundary conditions, type of part (deformable, analytical rigid), were taken into account. It was very important to observe the strip shape and the rolls crown behavior, because the interaction of both will provide the strip profile. The crown is produced by the load distribution, strip velocity and the strip size. Various different models were analyzed to provide a correct result on the strip profile and in the gap between the rolls. These models used different geometries with the objective to obtain the optimal parameters during a cold rolling process, the results were validated with data from the industrial process.

Keywords: Cold rolling, Flatness, 4 high mill

1. Introduction

The processes involved in the steel deformation are very important to different kind of industries. Steel is involved in so many industry fields because of its versatility, availability and reasonable cost. Flat rolling is a steel shaping process with two variations: the hot rolling and the cold rolling. The pieces rolled by hot rolling are thicker than those rolled by cold rolling. But to roll a strip in cold rolling, the strip must be rolled first at the hot strip mill.

Many types of mills are used to roll steel. This study considers a 4 high tandem cold mill composed by four stands, where two work rolls and two back up rolls are placed. The work rolls are in contact with the strip. It is studied how the cold rolling process and its variables affect the strip shape.

Flatness defects in the strip are very common, for this reason the control of process variables are object of study. When the defects are not controlled, the product can be rejected by the costumer. To classify the good or bad shape in the strip, a range established by the costumer in “I” units (UI) is used, the scale for a good strip shape is from 2 to 39 UI. The strip is evaluated with this range, and it can be accepted or rejected.

The strip shape is determined by changes in the strip thickness profile during the rolling process which in term replicates the roll profile along the length of the strip. The strip profile is defined as the strip thickness variation along the strip width in the perpendicular plane of the strip length (Deshpande, 1997). The profile is typically characterized by the strip crown. The following equation explains how the strip crown is calculated.

$$C = Y - \frac{(x_1 + x_2)}{2} \quad (1)$$

With the help of this equation the “I” units can be calculated as follows:

$$I = \left(\frac{C_1}{h_1} - \frac{C_2}{h_2} \right) - 10^5 \quad (2)$$

Where:

C_1/h_1 : Indicates the ratio between the entry strip crown and the entry thickness in a rolling stand.

C_2/h_2 : Indicates the ratio between the exit strip crown and the exit thickness in a rolling stand. (Miani, 2007)

Within the framework of a larger research on the influence of process variables in the resulting strip shape; this paper presents a comparison of several FEM models during the calculation of a single cold rolling pass.

2. Modelling

The model was prepared in Abaqus/CAE. Abaqus/Explicit solver was used due to the dynamic nature of the process.

2.1 Static model

The first model considered was a static case to establish the arc of contact between the work rolls and the strip. The model did not include the strip, but it was represented by a load. The load acted as a pressure over the area defined by the arc of contact. The load is illustrated in Figure 1. The arc of contact was calculated by equation 1:

$$L = \sqrt{R\Delta h} \quad (3)$$

Where Δh , is the difference between the thickness at the exit and at the entry end of the mill (Lenard, 2007).

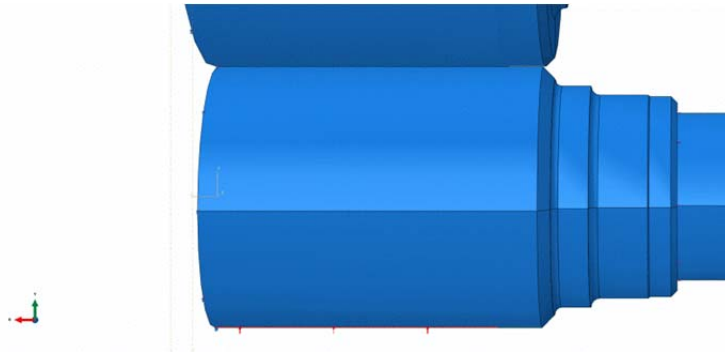


Figure 1. Pressure acting in the work roll.

In the dynamic model the strip is added and the friction coefficient between the rolls and the strip is calculated by equation 5.

$$\mu \geq \tan \alpha \quad (4)$$

$$\tan \alpha = \sqrt{\frac{\Delta h}{R}} \quad (5)$$

2.2 General model considerations

During modelling some considerations to the mill geometry were taken into account. One of the most important considerations related with the computational time was the vertical (Figure 2) and

horizontal symmetry of the mill (Figure 3). With this consideration the model is reduce just to a quarter of the model.



Figure 2. Vertical symmetry applied in a 4 high mill.

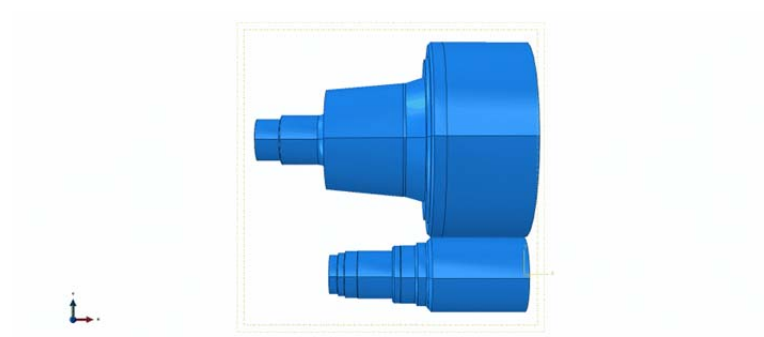


Figure 3. Vertical and horizontal symmetry applied to a 4 high mill.

The materials properties of the rolls are presented in the table 1. For the strip elastic plastic behavior was considered applying equation 6.

$$\sigma = 256 + 571\epsilon^{0.5} \quad (6)$$

Table 1. Rolls elastic properties.

Young Modulus (MPa).	Poisson Ratio
195 000	0.3

2.2.1 Boundary conditions.

The rotation in the work roll was applied as a boundary condition. Also the symmetry of the model, and Encastre in the Backup roll were applied as boundary conditions. The strip cannot go down due boundary conditions in the bottom. The strip velocity was determinate as a predefined field. The boundary conditions established in the models are illustrated in figures 4 and 5.

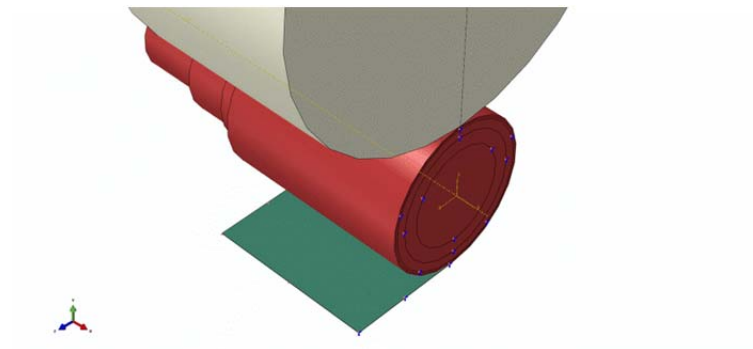


Figure 4. Dynamic model boundary conditions.

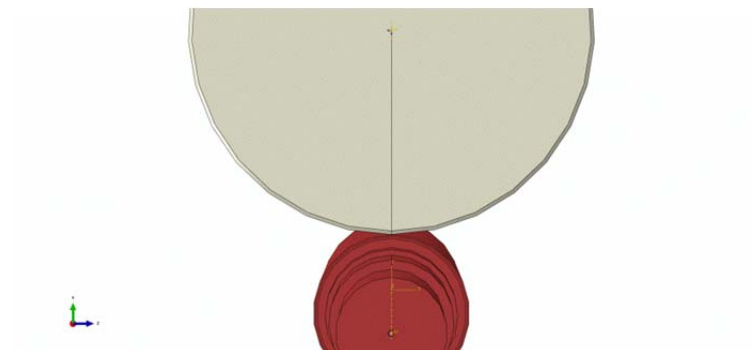


Figure 5. Boundary conditions in the Dynamic model.

2.3 Comparison of the cold rolling models

Four different models were run, to compare their response and select the one with the best results. Each model rotates the work roll in a different way. In three of these cases the work roll is considered deformable piece. In table 2 the models and their characteristics are listed.

Table 2. List of models analyzed in this research.

Model	Characteristics
M1	Rigid analytic work roll
M2	Work roll rotated by a circular plate
M3	Work roll rotated by a tube across the roll
M4	Work roll rotated by a tube in the neck of the roll

2.3.1 Rigid analytic work roll

To prove the correct behavior of the variables in the model, a simulation with the work roll as a rigid analytic was created. The figure 6 illustrates the rigid analytic work roll model. The strip in this model is reduced appropriately, proving that the strip properties and the assembly were correctly assigned.

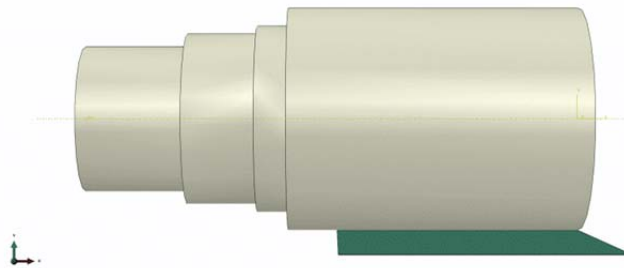


Figure 6. Rigid work roll and strip, in the rigid analytic work roll model.

Even if the solution of this model is fast and the behavior of the strip can be observed, this model cannot be used for these purposes because the profile in the work roll is not generated. However it

was probed that the strip position in relation to the work roll was correct. Other values like friction, strip speed and roll rotation were also evaluated in this model.

The mesh of this model is composed by 12,390 linear hexahedral elements of type C3D8R.

2.3.2 Work roll rotated by a circular plate.

With the purpose to reproduce the correct response of the work roll to the cold rolling variables, some adaptations were applied. In this case the rotation of the work roll was produced by a circular plate tied to the edge of the roll. Where the master surface is the plate and the slave surface is the circular area at the roll's edge.

Figure 7, illustrates the circular plate defined as an analytical rigid. The rotation and the contact conditions between the plate and the work roll were assigned using a reference point (RP). The assembly of the work roll, the strip and the plate is illustrated in figure 8. It can be observed that the diameters of the circular plate and the work roll edge have the same dimensions.

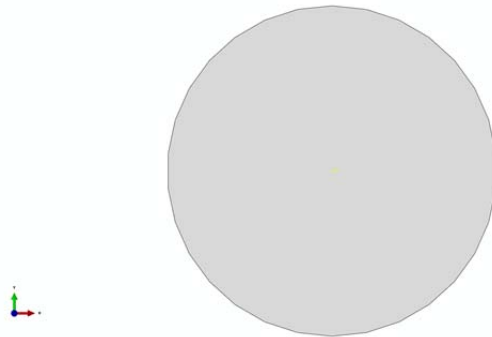


Figure 7. Circular plate.

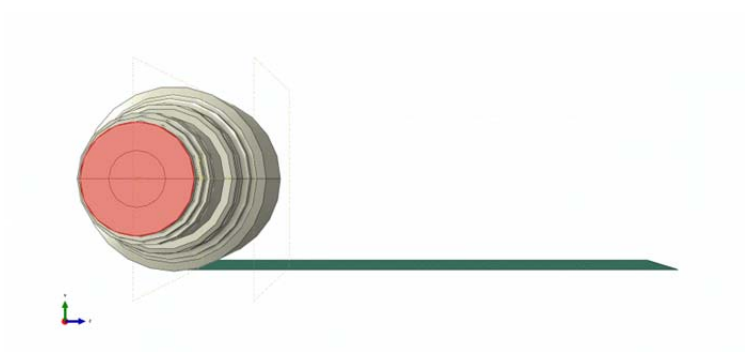


Figure 8. Interaction between the plate and the work roll.

The mesh of this model is composed 563190 linear hexahedral of type C3D8R.

2.3.3 Work roll rotated by a tube across the roll.

Another strategy to produce the rotation of the solid deformable piece was to create a new part in the model. This part is a rigid tube, situated across the work roll at the center (figure 9).



Figure 9. Rigid analytical tube.

With this analytical rigid part the rotation is produced using a tie constraint between the tube and the work roll. The rotation speed was defined at a reference point situated at the roll center (figure 10).

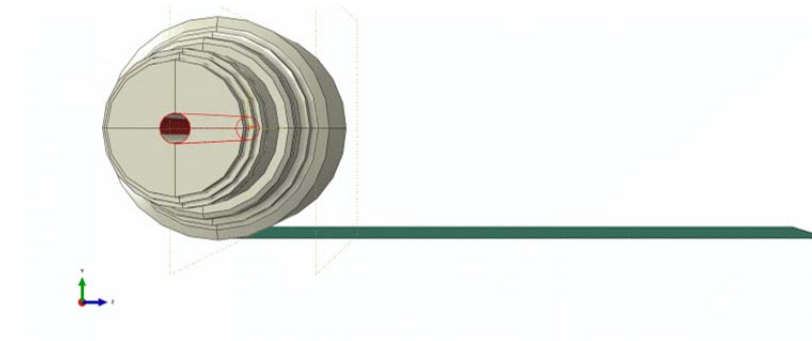


Figure 10. Assembly of the rigid tube with the work roll.

The work roll mesh used in the past two models could not be used in this case. It was necessary to create a new mesh considering the space of the tube across the roll.

The mesh of this model is constituted by 563190 linear hexahedral elements of C3D8R.

2.3.4 Work roll rotated by a tube in the neck of the roll.

The strategy of the tube across the roll was good, but it also interfered with the response of the work rolls to the variables of the process. In this model a tube as an analytical rigid part was also created, but the tube is situated only across the neck of roll. The assembly of this model is illustrated in the figure 11. With this assumption the tube did not interfere with the work roll deflection.

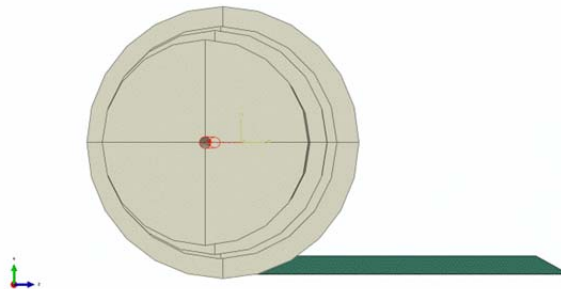


Figure 11. Rigid tube across the work roll neck.

2.3.4.1 Mesh

The mesh of this model is composed by 371222 Elements and 427755 nodes (table 3)

Table 3. Number and type of elements in Dynamic model.

Element type	Number
Linear hexahedral C3D8R	366802
Linear wedge C3D6	4420

The elements in the strip use hourglass control: Stiffness.

3. Results and discussion

After analyzing the behavior of the work roll with the strip. The model composed of the tube across the neck of the work roll was selected. This model produces a correct rotation in the work roll and does not affect its bending.

As mentioned before the model with the rigid work roll cannot be used in this analysis due the profile between the rolls is indispensable to this research. On the other hand the circular plate at the work roll edge produce a non-expected rotation, making a twist in the work roll edge and moving incorrectly the roll.

The results from the model with tube across the work roll show how the tube interferes with the roll bending. This affects the interaction between the roll and the strip and produces an error in the prediction of the roll behavior. The model with the short tube across the neck of the roll models correct the work roll rotated without interferences in the bending. The backup roll is necessary to avoid incorrect results in the strip shape.

After running this model the strip reduces 0.232 mm. rather than the established initial roll gap. The position of the work roll supposes to produce a bigger reduction, but an important factor considered when the deformation is measured is the spring back, which has not been taken into account in this model. The figure 12 shows the plastic deformation in the strip after the process.

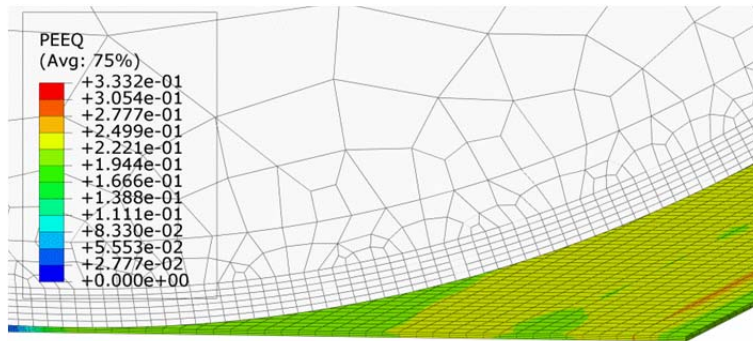


Figure 12. Plastic deformation in the strip.

The stresses between the rolls and the strip are an important factor in this research due the stresses and deformation. The strip reproduces the profile between the rolls all over the length. Figure 13 shows the stresses between the roll and the strip.

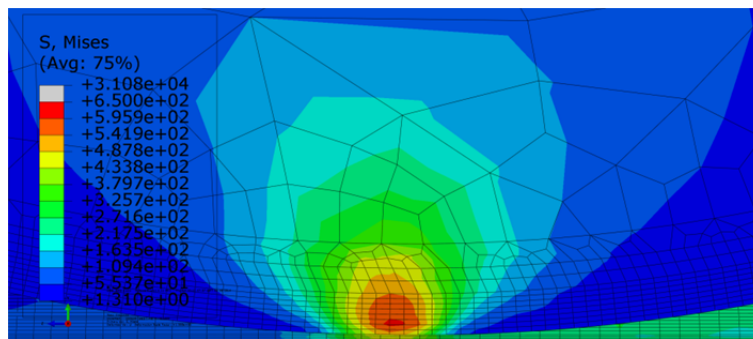


Figure 13. Stresses between work roll and strip.

The figure 14 shows the profile in the work roll during the rolling process.

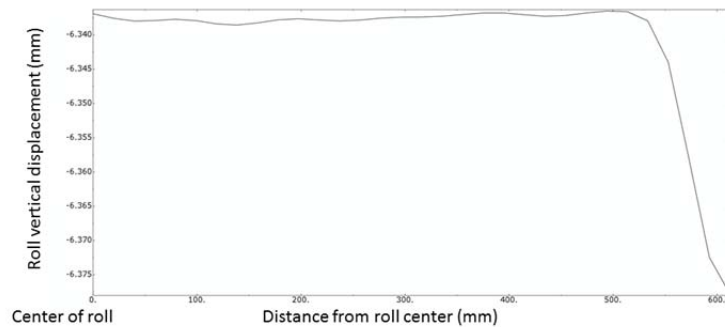


Figure 14. Work roll profile.

4. Conclusions.

The tube across the neck of the work roll represents correctly the cold rolling process. This tube does not interfere with the produced shape in the strip.

The backup roll is necessary to avoid imperfections in the strip shape. When the backup roll is not in the model the contact between the strip and the roll is intermittent.

The elements interacting between the strip and work roll contacts must be smaller to get a correct solution of the process response. At the center of the work roll the size of the elements were increased to reduce the computational time.

5. References.

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